Art. IX.—*Notes on Hydrology.*

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[Read 14th June, 1883.]

The subject which I have the honour to submit to you this evening, Hydrology, is a very extensive one; but I purpose referring only to the subject of rainfall, more particularly the rainfall in Sandhurst, and some of the results of my own observations during a long residence there.

Rainfall is, I believe, the most capricious of the elements, as it is governed or influenced by so many varying forces, and the laws which govern it are most complex. The general laws which govern it are being studied, and it is anticipated that some of them may be generalised, so that though it may be impossible to govern the rain, yet we may in the future be better enabled to prepare for the inevitable.

The object with which I have observed rainfall has been, primarily, its effect in causing floods, and to arrive at reliable data for providing for it. With that object in view I constructed a simple recording rain-gauge, consisting of a cylindrical gauge, into which rain from a known area was conveyed. A light metal float actuated a couple of pencils which recorded the rainfall, first on a drum which revolved in an hour, and secondly on a drum which revolved in twenty-four hours. After a heavy fall of rain it was an easy matter to scale off the quantity that fell in any period of time.

Rain, as is well known, is water which has been evaporated carried by currents of air and condensed by cooling. Air has the power of absorbing varying quantities of moisture increasing with the temperature. Hence a cube foot of air at 32° can absorb $3\frac{1}{2}$ grs.
at 86° „ „ 14 grs.
at 140° „ „ 56 grs.
and so on, so that if warm air, saturated, is cooled it will discharge water, and it is well known that the greater the heat the more rapid the evaporation.

The movements of the winds which carry these vapours have been most ably explained very recently by our esteemed President.

We will briefly consider under what circumstances rain falls generally. First, the air must be laden with moisture and must necessarily be warm, and to obtain that moisture it must come over extensive areas of water—the ocean. On coming in contact with cooler currents of air, cooler lands and trees, the moisture is condensed in the form of rain, and also when warm air, saturated with moisture, is mixed with a cooler air also saturated a discharge of moisture takes place, but to a very small extent. Where the vapours are carried inland until they come in contact with high mountain ranges, there the moisture is thrown upwards and is condensed, and the air which is then cooled passes over the mountain range with less moisture in it and in a state to absorb moisture instead of discharging; and it is found to be almost universal that the coast-line of continents is wet, and inland is dry, more particularly if the coast is bounded by mountain ranges.

It is found to be the case in India, where the south-west monsoons, which blow towards the north in summer (the sun being north of the equator), are laden with moisture from the Indian Ocean come in contact with the Western Ghauts, and the bulk of the moisture is discharged at about the height at which the clouds float. At one station there—Mahabulshwur—the rainfall for an average period of five months per annum is 245 inches, upwards of 20 feet; in 1849 it amounted to 338 inches; 10 to 13 inches often fall in one day, and as much as 130 inches in a month. The quantity rapidly falls off at a higher elevation, and also lower down, that is, above and below the average height of the line of cloud flotation; but on the eastern side of the mountain, only 11 miles distant, at another station—Paunchgunny—the average is only 50 inches per annum; and further east is the Deccan (or dry country), where the rainfall is only from 16 to 20 inches. This is, I believe, the most remarkable instance of the decrease of rain when intercepted by mountains. Then, at the head of the Bay of Bengal, Calcutta, being low, receives 60 to 80 inches per annum, but in some parts of the Himalayas, north of Calcutta, the rainfall is said to amount to as much as 600 inches per annum. The same rule holds good in Great Britain. The moisture from the Atlantic is condensed in Westmoreland and Cumberland at from 80 to 150 inches, whereas on the east side it varies from 18 to 24 inches per annum.

The same rule holds good with regard to Europe, as we recede from the Atlantic—Greenwich, 24 inches; Paris, 23 inches; Vienna, 19 inches; St. Petersburg, 15 inches

Catherineburgh, 12 inches; Barnaval, 9 inches. The same rule holds good with regard to the coast of America; and the same rule applies also to Australia. In New South Wales the coast rains from Antony and Clarence Rivers to Botany average about 50 inches, whereas inland it ranges from 10 to 16 inches per annum. In South Australia—at Mount Lofty, 42 inches; Charleston, 34 inches; Cape Borda, 27 inches; Bullaranga, 32 inches; Adelaide, 21 inches, near the coast; but inland, in the valley of the Murray, it ranges from 10 to 15 inches, and inland towards Stuart's Creek it is from 6 to 10 inches only.

Then again at Southport, near the coast, on the Overland Telegraph route, the rainfall is about 90 inches; further inland, Daly Waters, 35 inches; and further again, at Charlotte Waters, only 10 inches.

In Victoria our heavy rains are between the coast and the dividing range, and the lightest are on our north-west plains.

Taking the rainfall for last year, the heaviest, 60 inches, is at a place called Beenak, in the Yarra basin, hemmed in by a kind of horseshoe of mountains, with the open end facing south-westerly towards the sea. Then at the dividing range near Woodend, 49 inches; Blackwood, 43 inches; Macedon Nursery, 31·6 inches; Bungaree, 32·9 inches. Then along the coast—Portland, 30·3 inches; Warrnambool, 25 inches; Otway, 30 inches; Wilson's Promontory, 38·7 inches.

Then to the northern side of the dividing range there is a marked reduction—Castlemaine, 24·7 inches; Crusoe, 24·6 inches; Sandhurst, 21·6 inches; Heathcote, 23 inches. Further on the reduction is still more marked—Whroo, 19·7 inches; Elmore, 19·7 inches; and Echuca, 14·3 inches. If we start again, at Maldon, with 22·9 inches; Inglewood, 18 inches; Boort, 16·7 inches; and Kerang, 13·1 inches. Still again, on the Wimmera—Stawell, 18·1 inches; Horsham, 14·6 inches; Dimboola, 10·9 inches.

We have the sea to the south-east, south, and south-west of us. South-east winds bringing moisture are carried over the Australian Alps and mountains of Gippsland, condensing much of its moisture before it reaches us, and still more by the time it reaches the Sandhurst district. Moreover, they come down on us from cool elevated regions to a warmer climate, particularly in summer. Then winds from the south and a little east of south are comparatively cold, and do not carry so much moisture as the more easterly or westerly winds. The winds from the south are cool to start with; they come across the high lands of Tasmania, part with a portion of their small amount of moisture there; more moisture is collected in the Straits, which is condensed between Melbourne and the dividing range about Blackwood and Macedon; and the last few drops are squeezed out about Mount Alexander and the Big Hill Ranges, arriving at Sandhurst a cold dry wind, so that rain is never by any chance received there with a south wind. Often have I seen the sky with every appearance of rain, but no matter how threatening with a south wind no rain is received, excepting possibly a very few drops at the commencement. Not only is there no rain, but the sky becomes perfectly cloudless. The south-west winds arrive laden with moisture comparatively warm over the least mountainous portion of our colony, and it is from that direction most of the heavy rains are received in Sandhurst during the winter.

It appears to me that in summer time the moisture is brought from the sea with south-west winds; finding the land warm it is not condensed, but is carried inland over the plains into Central Australia, gathering more moisture by being more heated. The vapours then return with north-east, north and north-west winds from a hot to a cooler locality, and when deflected upwards by the first heavy timber or high lands are condensed in heavy storms of short duration.

Elevation has also an influence on the amount of rainfall, which may be easily understood if we bear in mind that the vapour of water is lighter than air at the sea-level. This vapour is invisible; when it changes into clouds it is changed partially into water. It is not known thoroughly how the clouds are supported; there are several theories on the subject. Nevertheless we know that clouds carrying large quantities of moisture generally float several thousand feet above the sea-level, and the greatest amount of rain may naturally be supposed to fall at that elevation, decreasing in higher and lower elevations. This has been noticed particularly on the Ghauts in India.

Clouds sometimes attain an altitude of upwards of 20,000 feet, but they cannot possibly carry much moisture.

Respecting seasons of floods and droughts, the knowledge of the general laws is at present very limited. Mr. Todd, of South Australia, has pointed out that years of drought are observed to be years of mean higher barometric pressure, and has shown that in South Australia the seasons of drought and floods follow in some sort of cycle. Mr. Russell, of New South Wales, appears to attach some weight to a nineteen-year cycle. I believe I am correct in stating that in England, where they have the advantage of a very extensive range of observations, no satisfactory cyclic series can be arrived at; and I have never heard Mr. Ellery's opinion respecting Victoria.

Some years since I was under the impression that we had a cycle of seven years, for the following reasons:—In Melbourne, 1842 was a wet year and a year of floods; 1849 the wettest in white man's time; 1856, 1863, 1870, periods of seven years, and very wet years—viz., 1842, 31 inches; 1849, 42 inches; 1856, 30 inches; 1863, 36 inches; 1870, 33 inches; 27 inches being the average; but to upset the seven-year idea, 1875 was the wet year, with 33 inches, and 1877, which ought to have been wet, only supplied 24 inches; so I gave up my long-cherished idea in disgust, and the nineteen-year theory will not apply. The dry years are much more irregular. For a period extending from 1840 to date, excepting a few years (1851 to 1854, no records), the driest seven years have been—1865, 15·9 inches; 1868, 18·2 inches; 1879, 19·2 inches; 1843, 21·5 inches; 1859, 21·8 inches; 1862, 22·0 inches; 1866, 22·4 inches.

The wettest seven years—1849, 42·2 inches; 1863, 36·4 inches; 1870, 33·7 inches; 1848, 33·1 inches; 1875, 32·8 inches; 1872, 32·5 inches; 1842, 31·1 inches.

The number of wet days in a year varies greatly—from 107 days in 1866 to 165 days in 1863.

In Sandhurst the average rainfall for twenty years is 21·7 inches, varying from 10·9 inches in 1865 to 38·3 inches in 1870. The rains are fewer, and of shorter duration, as a rule, than in Melbourne—in 1877, 64 days on which rain fell; 1876, 65 days; the greatest number being 132 days, in 1863, the average being about 99 days a year.

Rainfall, Sandhurst, 1861 to 1882.

Average	...	21·73	inches per annum	
Least rain	...	10·95	„	in 1865
Most rain	...	38·36	„	in 1870
Rain = Average	...	21·74	„	in 1867

Seven years over average and twelve years under.

On examining monthly rainfall I find there was—

No rain	1 month	in	1865
„	1	„	1878
„	1	„	1880

43 months	under ½ inch			
35	„	½ inch	to	1 inch
78	„	1	„	2 inches
52	„	2 inches	to	3 „
28	„	3	„	4 „
6	„	4	„	5 „
6	„	5	„	6 „
4	„	6	„	7 „

1 month over 7 inches, which was Oct., 1870.

During the same period—

Upwards of	1 inch	fell in	24	hours	59 times
„	2 inches	„	24	„	10 „
„	3 „	„	24	„	5 „
„	2 „	„	48	„	17 „
„	4 „	„	48	„	1 time, March 15th and [16th, 1878.

Our rains are heavier than Melbourne, but not so heavy as Sydney, and they are heavier still in Queensland.

I believe the heaviest rain of short duration in Melbourne was 10th March, 1877, when 1 inch fell in 15 minutes; rate, 4 inches per hour.

At Ballarat, February or March, 1876, 1·81 inch fell in 20 minutes; rate, 5·43 inches per hour.

At Sandhurst, of which I have any record, 12th December, 1875, ·5 inch in 5 minutes; rate, 6·0 inches per hour.

At Sydney, August, 1878, 1 inch fell in 6 minutes; rate, 10 inches per hour.

The heaviest 24 hours' rain recorded in—

Sandhurst,	3·67 inches,	occurred	16th March, 1878
Melbourne,	3·10 „	„	9th December, 1860
Beechworth,	6·00 „	in 30 hours, occurred	31st Aug., '75
Sydney,	20·41 „	occurred	15th October, 1844, when 5·4 inches fell in 2 hours.
Adelaide,	3·15 inches,	on	4th April, 1860

The following are also a few exceptionally heavy rains—

Townsville (Qld.)	20 inches	in 3 days,	25th Feb., 1877
Sydney ...	1·72 „	30 minutes,	6th Feb., 1878
„ ...	10·88 „	48 hours,	7th Feb., 1878
„ ...	7·00 „	4 hours,	5th April, 1882
Adelaide ...	7·8 „	10 days,	June, 1848

In England—

Greenwich ...	1 inch in 15 minutes,			25th July, 1852
Wandsworth ...	2·17 inches in 2 hours,			12th June, 1859
Southampton ...	2·05	„	2¼ „	26th Sept., 1859
Neville { Holborn, London	4·00	„	1 „	1st Aug., 1846
Neville { Highgate „	3·50	„	1 „	„ „
Neville { Greenwich ...	·95	„	1 „	„ „
Westminster, Vauxhall, and Lambeth ...	4·00	„	3 „	„ „
Nottingham ...	3·25	„	1 „	13th Aug., 1857
Little Bridge ...	·68	„	4½ min.,	29th Sept., 1855

Average Yearly Rainfall.

Sydney ...	51·46	inches
Melbourne ...	27·13	„
Sandhurst ...	21·73	„
Adelaide ...	21·09	„
England ...	38·00	„
London ...	24·00	„
Ireland ...	36·00	„
France ...	31·00	„
Spain ...	22·00	„

The following are some of the heaviest rates per hour of rainfall in Sandhurst, for various short periods since 1877—

Minutes—	1	2	2½	3	4	5	6	7	15	18½	20	25	30
9th Feb., 1878 ...	-	-	-	-	-	-	-	-	2·88	-	2·68	-	2·00
26th Feb., 1880 ...	-	-	-	-	-	-	2·8	-	-	-	-	1·28	·90
21st March, 1880 ...	-	-	3·6	-	-	2·8	-	2·6	-	1·78	-	-	-
26th October, 1882	4·8	4·3	-	3·8	3·4	3·0	2·5	2·4	-	-	-	-	-
28th Nov., 1882 ...	6·3	5·7	-	5·5	5·1	4·7	-	4·2	-	-	-	-	-

Rainfall, 4 a.m., 22nd April, 1882, to 3 p.m., 24th April, 1882, 3·66 inches; heaviest in 1 hour during the same period, ·66 inch.

Heavy Falls in Sandhurst in various short Periods.

				Rate per hour.
31st Dec., 1863 ...	3 inches	in	3½ hours ...	·85 inches
8th Feb., 1864 ...	·83	„	1 „ ...	·83 „
7th Sept., 1870 ...	·75	„	15 minutes ...	3·00 „
14th March, 1874 ...	·46	„	24 „ ...	1·15 „
13th Feb., 1875 ...	·55	„	10 „ ...	3·30 „
12th Oct., 1875 ...	·50	„	5 „ ...	6·00 „
11th Feb., 1877 ...	2·50	„	75 „ ...	2·00 „
11th Feb., 1878 ...	1·13	„	90 „ ...	·75 „
19th Oct., 1882 ...	·40	„	5 „ ...	4·80 „

The following is a list of the mean number of wet days per month in Sandhurst for 20 years ending 1881; the mean monthly rainfall; mean intensity per wet day; the maximum and the minimum :—

Month.	Mean wet days.	Mean rain. Inches.	Intensity per wet day. Inches.	Maximum per month. Inches.	Minimum per month. Inches.
January	4·25	1·44	·33	3·75	·0
February	3·95	1·46	·34	6·36	·01
March	5·10	1·46	·31	6·10	·06
April	8·15	1·79	·22	5·21	·35
May	10·25	2·02	·20	3·84	·37
June	11·40	2·54	·22	6·24	·26
July	11·50	1·89	·15	4·29	·14
August	12·85	2·15	·16	5·23	·26
September	10·65	2·24	·21	5·85	·27
October	9·30	2·34	·24	7·63	·17
November	6·40	1·48	·23	6.47	·00
December	5·25	·94	·18	4·90	·01

Mr. Ellery has kindly supplied me with the following list of rainfalls at Melbourne :—

Date	Rainfall	Time	Rate per hour.
1859—June 14	·57 inches in	1 hour	·57 inches
1860—Sept. 8	·50 „	1 „	·50 „
Dec. 9	3·10 „	12 „	—
1861—Jan. 31	2·37 „	11 „	—
Mar. 19	1·00 „	3 „	—
1862—Dec. 8	·48 „	25 minutes	1·15 inches
1863—Oct. 12	·85 „	12 hours	—
Nov. 22	·96 „	8 „	—
1864—Mar. 2	1·18 „	30 minutes	2·36 inches
April 12	1·10 „	12 hours	—
1867—April 6	·86 „	12 „	—
1870—Jan. 3	1·08 „	4 „	—
Jan. 25	1·52 „	12 „	—
1871—Feb. 7	1·89 „	9 „	—
Aug. 8	1·30 „	9 „	—
Nov. 22	·62 „	15 minutes	2.48 inches
1872—Nov. 19	·43 „	20 „	1·29 „
1877—Mar. 10	1·00 „	15 „	4·00 „
April 21	1·76 „	7 hours	—
1878—Mar. 15	2·12 „	12 „	—
1882—Dec. 5	1·25 „	1 „	1·25 inches

I fear that by this time I must be wearying you with statistics, and as I am not a professional lecturer, and consequently lack the art of making figures pleasant, I will as rapidly as possible draw to a close.

The value of a knowledge of the rainfall in all its varying phases is of special use to the engineer. By knowing the heaviest monthly, weekly, daily, and hourly rain, and also the maximum fall for still shorter periods, he is better enabled to calculate the necessary sizes of bridges, culverts, and water conduits. Of course other data are also necessary, such as the nature of the surface and subsoil, the general inclination of the ground, and the state of the surface.

The method adopted generally for fixing the dimensions of bridges over large rivers, viz., gauging the velocity and obtaining numerous cross-sections of the largest known floods will not apply to artificial watercourses, and is, in my opinion, unreliable when applied to the partially dry creeks of Australia, for the reason that the channels generally vary very greatly, the sectional area being in some cases very much larger at one spot than probably a short distance lower down. Furthermore, information of this kind is generally unreliable. Excessively high floods may be caused by obstructions which were not noted by the observer subsequently removed. Information of this kind is necessary, but it is equally necessary that something of the local hydrology should be also known and applied.

In my opinion, to estimate the requisite waterway at a certain point, it is necessary to know the area and form of the watershed; next the levels to find the time it will take the first drop of water to travel from the greatest distance to the culvert or bridge; then to know what proportion of the water soaks into the ground, and what portion is held back, and the rainfall.

As an illustration, suppose an area of five acres, and the greatest distance the water has to travel ten chains, and assume the nature and inclination of the surface to be such that nine-tenths of the water flows off at the maximum period, and the water travels the ten chains in six minutes, we must then know the heaviest rain that falls in six minutes; for it is evident that if the storm only lasts four minutes the rain will have ceased for two minutes before the extreme particle of water will have reached the culvert—hence the flood will not be a maximum. Should the rain be uniformly heavy for eight minutes, it is also evident that the flood will arrive at its maximum in six minutes, stay so for two minutes, and then subside. In

Sydney we find that one inch fell in six minutes on one occasion. One inch on ten acres will supply 36,300 cubic feet, nine-tenths of which is 32,670 cubic feet. Again, suppose the inclination of the culvert, when of the proper size, to be such that the water will flow when full six feet per second, then the maximum discharge will be when the most distant particle, together with particles from every portion of the area, has reached the culvert—hence the area required will be fifteen feet sectional area of waterway, or one and a-half feet per acre, and it could not be larger.

Now, if we assume a river five hundred miles long, area, say, fifteen thousand square miles, say two hundred hours for water to travel, and one-half held back, then the maximum flood will be after two hundred hours' continuous rain; less would not make a maximum, and more would only maintain the maximum. Suppose the heaviest two hundred hours' rain to be five inches, and velocity of flood ten feet per second, we should then have—

$$\frac{\underset{\text{c. ft. per Sq. Mile.}}{2{,}300{,}000} \times \underset{\text{Sq. Miles.}}{15{,}000} \times \underset{\text{Inches.}}{5}}{200 \text{ hrs.} \times 3600 \text{ secs.} \times 10 \text{ ft. per sec.}} \times \tfrac{1}{2} = 12{,}000 \text{ sq. ft.}$$

$$= \tfrac{4}{5} \text{ sq. ft. area per square mile.}$$

A chalk or sandy basin may absorb the whole of a heavy rain.

I will conclude with the observed maximum discharge in cubic feet per minute per square mile of several rivers and watercourses, partly from Beardmore and other sources.

Area of Watershed.		Name.	Maximum discharged per minute per square mile.	
600,000	square miles	Nile at Cairo ...	36	cubic feet
886,000	„	Mississippi ...	67	„
180,000	„	Ganges at Benares..	428	„
3,890	„	Severn at Gloucester	193	„
3,086	„	Thames at Staines	129	„
4,570	„	Shannon at Killaloe	960	„
35,000	„	Rhone at Avignon	592	„
20,000	„	Garonne ...	1,110	„
900	„	Ardeche, 1857 ...	18,888	„
71	„	Loch Katrine ...	2,094	„
98 to 100	„	Ireland ...	544 to 900	„
100	„	Coliban, Victoria ..	6,000	„
$15\frac{2}{3}$	„	Bendigo Creek ...	15,400	„
$\frac{1}{10}$	„	Hargraves St., Sdst.	56,000	„

Exhibiting enormous differences.